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14. ABSTRACT
The overall goals of the proposed learning integrated object recognition for image exploitation research effort at the Center for Research in Intelligent Systems of the University of California, Riverside are to improve the performance and reliability of automated systems that can recognize objects in reconnaissance imagery acquired under dynamically changing conditions and for systems that can efficiently extract information from enormous image databases. This requires innovative techniques developed through fundamental scientific research in the fields of machine learning and computer vision. The research accomplished in this effort involves four specific areas:

1) Predicting the performance for recognition systems;
2) Automating methods to develop composite class models for SAR recognition;
3) Learning integrated physics-based fusion of IR and video for target detection; and
4) Learning concepts in images/videos.

This report summarizes the achievements in each of the four major research areas.

15. SUBJECT TERMS
Learning, Visual databases, target recognition

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Acknowledgements

This final report describes the progress and accomplishments made on the project entitled, "Learning Integrated Recognition for Image Exploitation," during the period from July 1, 2002 to June 30, 2003.

1. OBJECTIVES:

Four major research problems explored in this effort are:

- **Performance prediction for recognition systems**
- **Composite models for SAR recognition**
- **Learning integrated physics-based fusion of IR/Video for target detection**
- **Learning concepts in images/video**

2. ACCOMPLSHMENTS/NEW FINDINGS

Recognition Performance Prediction and Fundamental Performance Bounds

The focus of this research is predicting the bounds on performance of a vote-based object recognition system, when the test data features are distorted by uncertainty in both feature locations and magnitudes, by occlusion and by clutter. An improved method is developed to calculate lower and upper bound predictions of the probability that objects with various levels of distorted features will be recognized correctly. The prediction method takes model similarity into account, so that when models of objects are more similar to each other, then the probability of correct recognition is lower. The effectiveness of the prediction method is validated in a synthetic aperture radar (SAR) automatic target recognition (ATR) application using MSTAR public SAR data, which are obtained under different depression angles, object configurations and object articulations. Experiments show the performance improvement that can obtained by considering the feature magnitudes, compared to a previous performance prediction method that only considered the locations of features. In addition, the predicted performance is compared with actual performance of a vote-based SAR recognition system using the same SAR scatterer location and magnitude features.

We have extended the above approach for predicting the fundamental performance of fingerprint recognition. Fingerprints have long been used for person authentication. However, there is not enough scientific research to explain the probability that two fingerprints, which are impressions of different fingers, may be taken as the same one. We propose a formal framework to estimate the fundamental algorithm independent error rate of fingerprint matching. Unlike a previous work, which assumes that there is no overlap between any two minutiae uncertainty areas and only measures minutiae's positions and orientations, in our model, we do not make this assumption and measure the relations, i.e. ridge counts, between different minutiae as well as minutiae's positions and orientations. The error rates of fingerprint matching obtained by our approach are significantly lower than that of previously published research. Results are shown using NIST-4 fingerprint database. These results contribute towards making fingerprint matching a science and settling the legal challenges to fingerprints.

Publications:

E. Hong, B. Bhanu, G. Jones and X. Qian, "Performance modeling of vote-based object recognition," *Proceedings Radar Sensor Technology IX, Vol. 5077,* Orlando. FL, April 21-25, 2003.

X. Tan and B. Bhanu, "On the fundamental performance for fingerprint matching," *Proceedings IEEE Conference on Computer Vision and Pattern Recognition,* Vol. II, pp. 499-504, June 18-20, 2003.

Composite Class Models for SAR Recognition

The focus of this research is a genetic algorithms based method to automate the construction of local feature based composite class models that capture the salient characteristics of configuration variants of vehicle targets in SAR imagery and increase the performance of SAR recognition systems. The recognition models are based on quasi-invariant local features, SAR scattering center locations and magnitudes. The approach uses an efficient SAR recognition system as an evaluation function to determine the fitness of candidate members of a genetic population of new models and synthetically generates composite class models that are more similar to existing configurations than those configurations are to each other. Intuitively, specific features of models of versions A and B of an object may not match, because they are outside of some tolerance, while they may both match some synthetic version C that is somewhere in the middle. Experimental recognition results are presented in terms of receiver operating characteristic (ROC) curves to show the improvements in SAR recognition performance utilizing composite class models of configuration variants of MSTAR vehicle targets.

Publications:

B. Bhanu and G. Jones, "Composite class models for SAR recognition," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery X,* Vol. 5095, pp. 284-291, April 21-25, 2003.

Recognition of Human Articulated Motion

(a) In an infrared (IR) image sequence of a human walking, the human silhouette can be reliably extracted from the background regardless of lighting conditions and colors of the human surfaces and backgrounds in most cases. Moreover, some important regions containing skin, such as face and hands, can be accurately detected in IR image sequences. We propose a kinematic-based approach for automatic human motion analysis from IR image sequences. The proposed approach estimates 3D human walking parameters by performing a modified least squares fit of the 3D kinematic model to the 2D silhouette extracted from a monocular IR image sequence, where continuity and symmetry of human walking and detected hand regions are also considered in the optimization function. Experimental results show that the proposed approach achieves

good performance in gait analysis with different view angles with respect to the walking direction, and is promising for further gait recognition.

(b) Existing gait recognition approaches do not give their theoretical or experiential performance predictions. Therefore, the discriminating power of gait as a feature for individual recognition cannot be evaluated. We propose a kinematic-based approach to recognize individuals by gait. The proposed approach first estimates 3D human walking parameters by performing a least squares fit of the 3D kinematic model to the 2D silhouette extracted from a monocular image sequence. Next, a Bayesian based statistical analysis is performed to evaluate the discriminating power of extracted features. Through probabilistic simulation, we not only predict the probability of correct recognition with regard to different within-class feature variance, but also obtain the upper bound on probability of correct recognition with regard to different human silhouette resolution. In addition, the maximum number of people in a database is obtained given the allowable error rate. This is extremely important for individual recognition by gait in large databases.

Publications:

B. Bhanu and J. Han, "Kinematic-based human motion analysis in infrared sequences," *Proceedings IEEE Workshop on Applications of Computer Vision*, pp. 208-212, December 3-4, 2002.

B. Bhanu and J. Han, "Bayesian-based performance prediction for gait recognition," *Proceedings IEEE Workshop on Human Motion and Video Computing*, pp. 145-150, December 5-6, 2002.

B. Bhanu and J. Han, "Human recognition on combining kinematic and stationary features," *Proceedings International Conference on Audio- and Video-based Biometric Person Authentication*, pp. 600-608, June 9-11, 2003.

Moving Shadow, Vehicle and People Detection in Video

Moving object detection systems generally detect shadows cast by the moving object as part of the moving object. In this work the problem of separating moving cast shadows from the moving objects in outdoor environment is addressed. Unlike other previous work, we provide a method that does not use any geometrical information. Our physics-based approach is based on a new spatio-temporal albedo normalization test and a dichromatic reflection model. The physics based model is used both in the estimation and verification phases. We obtain results for several different video sequences representing a variety of materials and shadows. We achieve excellent results in distinguishing moving objects from their shadows. The results indicate that our approach is robust to a variety of background and foreground materials and varying illumination conditions.

We approach the task of human silhouette extraction from color and infrared video using automatic image registration. Image registration between color and thermal images is a

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challenging problem due to the difficulties associated with finding correspondence. However, the moving people in a static scene provide cues to address this problem. We propose a hierarchical scheme to automatically find the correspondence between the preliminary human silhouettes extracted from color and infrared video for image registration. We have developed strategies for probabilistically combining cues from registered color and thermal images. It is shown that the proposed approach achieves good results for image registration and human silhouette extraction. Experimental results also show a comparison of sensor fusion strategies and demonstrate the improvement in performance for human silhouette extraction.

Publications:

S. Nadimi and B. Bhanu, "Moving shadow detection using a physics-based approach," *Proceedings International Conference on Pattern Recognition*, Vol. II, pp. 701-704, August 11-15, 2002.

S. Nadimi and B. Bhanu, "Physics-based models for sensor fusion," *IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp. 161-166, July 29-August 1, 2003.

J. Han and B. Bhanu, "Detecting moving humans using color and infrared video," *IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp. 228-233, July 29-August 1, 2003.

Learning Semantic Concepts from Images and Video

(a) Increasing amounts of digital video data have become available with the rapid growth in video technology. As a result, there is a great need for automatic extraction of concepts or events of interest from video. In this research, we develop an approach for learning concepts from video. The approach consists of three steps. In the first step, video shot boundaries are detected, and from these shots key frames are extracted, which are representatives of the shots. In the second step, key frames are segmented and a variety of features are computed. In the third step, a classification by feature partitioning method is employed for learning different semantic concepts. The results are obtained for successfully learning semantic concepts such as ocean, mountain, people, and building from a variety of digital videos.

(b) In recent years feedback approaches have been used in relating low-level image features with concepts to overcome the subjective nature of the human image interpretation. Generally, in these systems when the user starts with a new query, the entire prior experience of the system is lost. In this work, we address the problem of incorporating prior experience of the retrieval system to improve the performance on future queries. We develop a semi-supervised fuzzy clustering method to learn class distribution (meta knowledge) in the sense of high-level concepts from retrieval experience. Using fuzzy rules, we incorporate the meta knowledge into a probabilistic relevance feedback approach to improve the retrieval performance. We have also developed novel techniques for semi-supervised EM (Expectation Maximization) algorithm, active learning and concept transplantation. Results on synthetic and real databases show that our

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approach provides better retrieval precision compared to the case when no retrieval experience is used.

Publications:

J. Liu and B. Bhanu, "Learning semantic visual concepts from video," *Proceedings International Conference on Pattern Recognition,* Vol. II, 1061-1064, August 11-15, 2002.

A. Dong and B. Bhanu "A new semi-supervised EM algorithm for image retrieval," *Proceedings IEEE Conference on Computer Vision and Pattern Recognition,* Vol. II, pp. 662-667, June 18-20, 2003.

A. Dong and B. Bhanu, "Concept learning and transplantation for dynamic image databases," *IEEE International Conference on Multimedia and Expo,* pp. 765-768, July 6-9, 2003.

A. Dong and B. Bhanu, "Active Concept Learning for Image Retrieval in Dynamic Databases," International Conference on Computer Vision, Oct. 2003.

3. PERSONNEL SUPPORTED:

Bir Bhanu, Grinnell Jones, Sohail Nadimi, Anlei Dong, Xuejun Tan, Ju Han, Lynne Cochran, Jeremiah Kent.

4. RELATED PUBLICATIONS (1 July 2002 to 30 September 2003)

(a) BOOK PUBLISHED/IN PRESS

B. Bhanu and X. Tan, "Computational Algorithms for Fingerprint Recognition," Kluwer Academic Publishers, 212 pages, December 2003.

(b) SPECIAL ISSUES OF JOURNALS PUBLISHED/IN PRESS

B. Bhanu, T. Boult, A. Gupta and D. Michael (Guest Editors), "Innovative Applications of Computer Vision," *International Journal of Machine Vision and Applications* **(Special Issue)**, Vol. 13, No. 3, pp. 109-184, 2002.

B. Bhanu, T. Boult, A. Gupta and D. Michael, "Introduction to the Special Issue on Innovative Applications of Computer Vision," *International Journal of Machine Vision and Applications,* Vol. 13, No. 3, pp. 109-110, 2002.

I. Pavlidis. and B. Bhanu (editors). Computer vision beyond the visible spectrum, *Image and Vision Computing* **(Special Issue)**, Vol. 21, No. 7, pp. 563-673, July 2003.

I. Pavlidis and B. Bhanu, "Guest Editorial: Special issue on computer vision beyond the visible spectrum," Vol. 21, No. 7, pp. 563-564, 2003.

(c) JOURNAL PAPERS PUBLISHED/IN PRESS

J.S. Ahn and B. Bhanu, "Model-based recognition of articulated objects," *Pattern Recognition Letters*, 23(8), pp. 1019-1029, August 2002.

B. Bhanu and A. Dong, "Concepts learning with fuzzy clustering and relevance feedback," *Engineering Applications of Artificial Intelligence*, 15, pp.123-138, Sept. 2002.

B. Bhanu and G. Jones, "Increasing the discrimination of SAR recognition models," *Optical Engineering*, Vol. 41, No. 12, Dec. 2002.

B. Bhanu and X. Tan, "Fingerprint indexing based on novel features of minutiae triplets," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 25, No. 5, pp. 616-622, May 2003.

X. Tan and B. Bhanu, "A robust two step approach for fingerprint identification," *Pattern Recognition Letters*, 24, pp. 2127-2134, June 2003. Special Issue on Biometrics.

B. Bhanu and Y. Lin, "Stochastic models for recognition of occluded objects," *Pattern Recognition*, December 2003.

B. Bhanu and Y. Lin, "Synthesizing feature agents using evolutionary computation," *Pattern Recognition Letters,* Special Issue on Remote Sensing. (accepted)

B. Bhanu and G. Jones III, "Multiple look angle SAR recognition," *International Journal of Imaging and Graphics*. (accepted, in Press)

(d) JOURNAL PAPERS (submitted but not yet accepted)

S. Nadimi and B. Bhanu, "Physical models for moving shadow and object detection in video," Submitted to *IEEE Transactions on Pattern Analysis and Machine Intelligence*, October 2002.

X Tan, B. Bhanu and Y. Lin, "Fingerprint classification based on learned features," Submitted to *IEEE Transactions on Systems, Man and Cybernetics,* Special issue on Biometrics, January 2003.

P. Yin, B. Bhanu, K. Chang and A. Dong, "Integrating relevance feedback techniques for image retrieval using reinforcement learning," Submitted to *IEEE Transactions on Pattern Analysis and Machine Intelligence*, May 2003.

A. Dong and B. Bhanu, "Active concept Learning in image databases," Submitted to *IEEE Trans. on Systems, Man and Cybernetics*, August 2003.

(e) CONFERENCE PAPERS PUBLISHED/ACCEPTED

S. Nadimi and B. Bhanu, "Moving shadow detection using a physics-based approach," *Proceedings International Conference on Pattern Recognition*, Vol. II, pp. 701-704, August 11-15, 2002.

J. Liu and B. Bhanu, "Learning semantic visual concepts from video," *Proceedings International Conference on Pattern Recognition*, Vol. II, 1061-1064, August 11-15, 2002.

B. Bhanu and J. Han, "Individual recognition by kinematic-based gait analysis," *Proceedings International Conference on Pattern Recognition*, Vol. III, pp. 343-346, August 11-15, 2002.

P. Yin, B. Bhanu, K. Chang and A. Dong, "Improving retrieval performance by long-term relevance information," *Proceedings International Conference on Pattern Recognition*, pp. Vol. III, pp. 533-536, August 11-15, 2002.

X. Tan and B. Bhanu, "Robust Fingerprint Identification," *IEEE International Conference on Image Processing*, Vol. I, pp. 277-280, September 22-25, 2002.

X. Tan and B. Bhanu, "Fingerprint verification using genetic algorithms," *Proceedings IEEE Workshop on Applications of Computer Vision*, pp. 79-83, December 3-4, 2002.

B. Bhanu and J. Han, "Kinematic-based human motion analysis in infrared sequences," *Proceedings IEEE Workshop on Applications of Computer Vision*, pp. 208-212, December 3-4, 2002.

B. Bhanu and J. Han, "Bayesian-based performance prediction for gait recognition," *Proceedings IEEE Workshop on Human Motion and Video Computing*, pp. 145-150, December 5-6, 2002.

B. Bhanu and J. Han, "Human recognition on combining kinematic and stationary features," *Proceedings International Conference on Audio- and Video-based Biometric Person Authentication*, pp. 600-608, June 9-11, 2003.

X. Tan, B.Bhanu and Y. Lin, "Learning features for fingerprint classification," *Proceedings International Conference on Audio- and Video-based Biometric Person Authentication*, pp. 318-326, June 9-11, 2003.

X. Tan and B. Bhanu, "On the fundamental performance for fingerprint matching," *Proceedings IEEE Conference on Computer Vision and Pattern Recognition*, Vol. II, pp. 499-504, June 18-20, 2003.

A. Dong and B. Bhanu "A new semi-supervised EM algorithm for image retrieval," *Proceedings IEEE Conference on Computer Vision and Pattern Recognition*, Vol. II, pp. 662-667, June 18-20, 2003.

A. Dong and B. Bhanu, "Concept learning and transplantation for dynamic image databases," *IEEE International Conference on Multimedia and Expo*, pp. 765-768, July 6-9, 2003.

X. Tan and B. Bhanu, "Fingerprint identification: classification vs. Indexing," *IEEE International Conference on Advanced Video and Signal-based Surveillance*, pp. 151-156, July 21-22, 2003.

S. Nadimi and B. Bhanu, "Physics-based models for sensor fusion," *IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp. 161-166, July 29-August 1, 2003.

J. Han and B. Bhanu, "Detecting moving humans using color and infrared video," *IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp. 228-233, July 29-August 1, 2003.

A. Dong and B. Bhanu, "Active Concept Learning for Image Retrieval in Dynamic Databases," International Conference on Computer Vision, Oct. 2003.

P. Yin, B. Bhanu, K. Chang and A. Dong, "Reinforcement learning for combining relevance feedback techniques in image retrieval," International Conference on Computer Vision, Oct. 2003.

B. Bhanu and G. Jones, "Composite class models for SAR recognition," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery X*, Vol. 5095, pp. 284-291, April 21-25, 2003.

E. Hong, B. Bhanu, G. Jones and X. Qian, "Performance modeling of vote-based object recognition," *Proceedings Radar Sensor Technology IX, Vol. 5077*, April 21-25, 2003.

5. INTERACTIONS/TRANSITIONS:

a. Participation/presentations at meetings, conferences, seminars,

Panelist on Adaptive Recognition Technology, (April 2003, Orlando, FL) panel organized by Mr. Ed Zelnio from AFRL with DARPA and AFRL participation.

Panelist on Evolutionary Computation Research at the GECCO 2003 conference, July 2003.

Panel Member GECCO Workshop on Understanding coevolution: theory and analysis of coevolutionary algorithms, July 9, 2002.

General Chair, IEEE Workshop on Learning in Computer Vision and Pattern Recognition, June 2003.

Participated in Program Review, AFOSR, Syracuse, June 2003.

Session Chair, International Conference on Pattern Recognition, August 11-15, 2002; Genetic and Evolutionary Computation Conference, July 2002, 2003; International Biometrics Conference, May 2003.

Program Committee Member, International Conference on Pattern Recognition, August 11-15, 2002; International Conference on Signal and Video Surveillance, July 2003.

b. Invited by Dr. Dale Nelson, Branch Chief and Mr. Ed Zelnio, ATR Division Chief to participate in the AFRL ATR Workshop held on Oct. 17-18, 2002 at Dayton, OH. PI held discussions with various AFRL personnel, including Dr. Nelson, Mr. Ed Zelnio, Dr. Greg Power and Dr. Tim Ross. Dr. Ross is interested in defining challenge problems for learning related adaptive ATR technology. We had several conversations during the last year.

PI had conversation and e-mail exchanges with Dr. Mike Talbert of AFRL. Dr. Talbert has recently moved to AFIT from Rome, NY. He is interested in collaboration on image/video database research. Currently we are investigating the details.

c. Our research makes fundamental contributions to the open research problems of great importance to the DoD community. In particular, our basic contributions in the target and object recognition in video, IR and SAR images and information retrieval area are applicable to many practical applications.

6. NEW DISCOEVRIES, INVENTIONS, OR PATENT DISCLOSURES

A book is about to be published (in Press, to be out by Dec. 2003) on commercial application of target recognition technology. The title of the book is *Computational Algorithms for Fingerprint Recognition*. The publisher is Kluwer Academic Publishers. Several invention disclosures will be filed based on the material in this book.

7. HONORS/AWARDS

During the grant period: Elected a Fellow of SPIE, February 2003.

Life Time Achievement Honors:

Fellow -- American Association for the Advancement of Science (AAAS)
Fellow – Institute of Electrical and Electronics Engineers (IEEE)
Fellow – International Association of Pattern Recognition (IAPR)

Senior Fellow – Honeywell Inc.